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Bibliographical Review on the Importance of Moroccan Lagoons for Integrated and Sustainable Aquaculture

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ABSTRACT

Moroccan lagoons are highly productive and diverse ecosystems, vital for biodiversity, tourism, aquaculture, and coastal protection. However, they face increasing threats from human activities and natural pressures, jeopardizing their ecological integrity. The objective of this bibliographical review was to assess the ecological significance and potential for sustainable aquaculture development of six major Moroccan lagoons: Nador and Smir (Mediterranean coast) and Moulay Bousselham, Sidi Moussa, Oualidia, and Khenifiss (Atlantic coast). We delved into their geographical and morphological contexts, physico-chemical and hydrodynamic characteristics, heavy metal contamination levels, and biological diversity. Our findings revealed diverse environmental conditions across the lagoons, impacting their biological communities. Notably, Oualidia and Khenifiss exhibited a high resemblance in species composition, dominated by mollusks, while Nador and Sidi Moussa share similarities with crustaceans as the prominent group. Smir and Moulay Bousselham displayed distinct profiles, with crustaceans being the most abundant. Heavy metal contamination varied significantly, with Nador and Khenifiss showing the highest levels. Despite their ecological importance, most lagoons experience anthropogenic pressures that impact their ecological integrity. This review highlights recommended aquaculture species for these lagoons, with a primary focus on shellfish and fish farming, as well as the high suitability for seaweed cultivation, particularly *Gracilaria*. Emphasizing the need for sustainable management strategies, it underscores the crucial role of Moroccan lagoons as potential hubs for integrated aquaculture.

INTRODUCTION

A coastal lagoon is a shallow expanse of brackish or salty water, partly separated from the nearby sea by a natural barrier of sand or shingle. Coastal lagoons occupy 13% of the world's coastline **(Barnes, 1989)**. Lagoons exhibit a wide variety of habitats and support diverse biological communities, with hydrology, physiognomy and geomorphology varying significantly from one lagoon to another **(Pôle-relais lagunes mediterranéennes, 2013)**. The complexities in terminology create challenges when delving into historical knowledge of these lagoon systems. To identify a coastal lagoon, three characteristics are utilized: (1) The existence of a separating barrier, such as a beach, spit, or a series of barrier islands; (2) the system retains most or all of its water mass, even during low tide in the adjacent sea; and (3) the constant natural exchange of water between the lagoon and the nearby sea occurs through percolation across or over the barrier, as well as through inlet and outflow channels, helping the lagoon preserve its saline or brackish character **(Barnes, 1989)**.

Lagoons are sensitive ecosystems requiring special protection. Over the past century, human impact has significantly affected these ecosystems, primarily through the introduction of anthropogenic contaminants **(Halpern *et al*., 2008; Waycott *et al*., 2009; Anthony *et al*., 2014; Mendoza-Carranza *et al*., 2016)**. Trace elements, in particular, pose a significant risk since they can accumulate in aquatic life and potentially affect human health **(Wei *et al*., 2016)**. Understanding and managing the physico-chemical parameters of these environments are crucial steps in mitigating further degradation and preserving their ecological integrity.

While these dynamic environments face challenges such as pollution and overexploitation, they also hold immense potential for sustainable development, particularly in the realm of aquaculture. When appropriately managed and adapted to the specific conditions of each lagoon ecosystem, aquaculture lagoon can play a vital role in enhancing fisheries production and supporting local economies. However, this potential is constrained by growing environmental pressures, including habitat degradation, eutrophication, and pollution, which must be carefully managed to ensure the long-term viability of aquaculture activities in these fragile ecosystems.

This article explored the potential of Moroccan lagoons for integrated and sustainable aquaculture, focusing on a comparative analysis of six key lagoons along both the Mediterranean and Atlantic coasts. This comprehensive survey aimed to provide information on the multifaceted dynamics of Moroccan lagoons, considering geographical, physico-chemical, hydrodynamic, heavy metal, biological richness, main species recommended for aquaculture, and socio-economic aspects.

Coastal lagoons in the northern African region, spanning Morocco, Algeria, Tunisia, Libya, and Egypt, are widely distributed. This article explored a comparison of six key lagoons in Morocco and their relationship with aquaculture: Nador and Smir along the Mediterranean coast, as well as Moulay Bousselham, Sidi Moussa, Oualidia, and Khenifiss on the Atlantic coast.

RESULTS AND DISCUSSION

1. Distribution of the different types of coastal lagoon in Morocco

In the Moroccan Mediterranean coastline

Table (1) shows the geographic coordinates and morphological parameters of the Moroccan lagoons, spanning both the Mediterranean and Atlantic coastal areas. The distribution of these lagoons is illustrated in Figs. (1, 2, 3) for the Mediterranean and Atlantic coasts, respectively.

Smir lagoon: The Mediterranean lagoon of Smir, in northwest Morocco (35°43'N, 5°20'W), is the most westerly lagoon in the Mediterranean basin (Fig. 1A). Covering an area of approximately 3km², with a maximum depth of 2.5 meters, this lagoon experiences a humid Mediterranean climate **(Chaouti & Bayed, 2005)**. It has been changed from a lake to a neutral littoral lagoon according to the classification of **(Postma, 1969; Bekkali, 1987; Aksissou, 1989; Aksissou & Elkaim, 1994, 1996)**. Historically fed by the Wadi Smir, its inflow has decreased since a dam was built in 1991 **(Messari & Bosch, 1995)**. This ecosystem is in communication with the port of Kabila, and opens onto the Mediterranean Sea through a gully, periodically subject to tidal movements, with an average amplitude of around 1 meter **(Chaouti & Bayed, 2005)**. Endowed with remarkable biodiversity, this lagoon complex, comprising a coastal lagoon, an artificial water body and a stretch of river **(Hajib & Bayed, 2005)**. It was designated as a RAMSAR site (Convention on Wetlands of International Importance) in 2019, highlighting its significance despite its relatively small size.

Nador lagoon: The Nador Lagoon, also referred to as "Marchica," is a lagoon ecosystem situated in northeastern Morocco along the Mediterranean coast (2°45’N – 2°55’N, 35°10’W) (Fig. 1B). This ecosystem has been classified as a RAMSAR site (Convention for the Protection of Wetlands) since 2005 and site of Biological and Ecological Interest (SIBE) since 1996. Covering an area of 115km², it stands as the largest lagoon in Morocco **(Berraho *et al.*, 1995)** and the second largest on the southern Mediterranean coast, following Tunisia’s El Bidan lagoon (330km^2) **(Lemoalle, 1986)**. The Nador Lagoon has a semi-arid climate, receiving an annual average of 354mm of rainfall and maintaining an average temperature of 19.6°C. This expansive lagoon, isolated from the Mediterranean Sea by a narrow sandbar (lido), is connected to the sea through a singular inlet known as the "Boukhana," measuring 250 meters in width. It spans dimensions of 25km in length and 7.5km in width. The lagoon is supplemented with freshwater inflow from the Oued Kabay, Oued Selouane, and Oued Areg rivers. The maximum recorded depth of the lagoon is 8 meters **(Zine & Menioui, 1998)**. According to the classification by **Hayes (1975)**, this lagoon falls under the microtidal type. Additionally, it is characterized as anti-estuarine based on the classification by **Postma (1969)**, complemented by the semi-enclosed type according to **Nichols and Allen (1981)** separated from the Mediterranean Sea by a dune belt known as the "Lido".

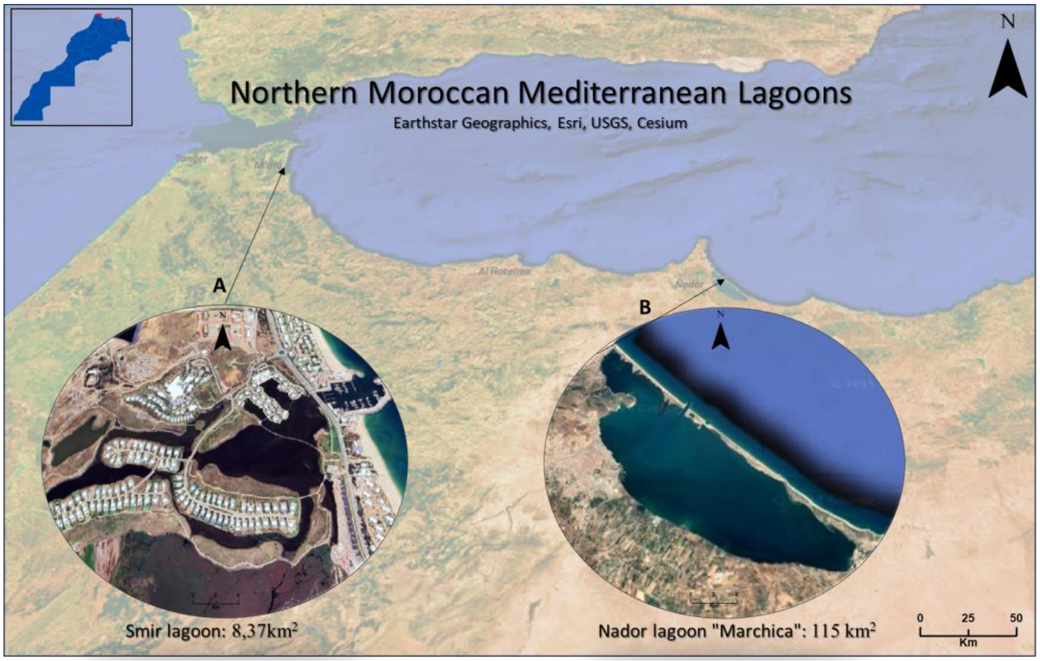

Fig. 1. Distribution of lagoons on the Mediterranean coast of Morocco. Map created using ESRI ArcGIS. **(A)** Smir lagoon, **(B)** Nador lagoon

In the Moroccan Atlantic coastline

Moulay Bousselham lagoon: The Moulay Bousselham lagoon, also known as Merja Zerga, is positioned 125km north of Rabat (34° 50' 30"N, 6° 17' 30"W), covering 35km² (Fig. 2A). Its elliptical shape extends up to 9km in length and 5km in width. The climate of the Moulay Bousselham lagoon is characterized by a temperate Mediterranean climate featuring hot and dry summers (Csa). It is classified as microtidal per **Hayes (1975)** and semi-enclosed according to **Nichols and Allen (1981)**. The lagoon is in constant communication with the Atlantic Ocean through a single 50-meter-long inlet. It benefits from substantial freshwater inflows, notably from the Oued Drader to the northeast and the Nador canal to the south **(Labbardi *et al*., 2005)**. The lagoon's depth varies from 0 to 2, influenced by the tidal cycle and rainfall **(Kraïem *et al*., 2001)**. Designated as a Ramsar site since 1980, acknowledging its international wetland importance.

Sidi Moussa lagoon: The Sidi Moussa lagoon is part of the same Oualidia coastal complex (32° 52' 0"N, 8° 51' 05"W). Its total surface area is 4.2km^2, with a length of 5.5km and a width of 0.5km. It is located approximately 41km south of El Jadida **(El Khalidi *et al*., 2011)** (Fig. 2B). This lagoon is neutral as per **Postma (1969)**, mesotidal per **Hayes (1975)**, and estuarine according to **Nichols and Allen (1981)**. This lagoon is also classified as a RAMSAR site and one of the most important wetlands in Morocco, for its importance in safeguarding rare birds. The climate is Mediterranean with an oceanic influence. It is separated from the Atlantic Ocean by a dune ridge interrupted by two inlets at the downstream end of the lagoon: the main one, to the southeast, is 150 meters wide, while the secondary (temporary) one, to the north of the main one, is 50 meters wide, allowing it to communicate with the sea **(Daghor *et al*., 2016)**. The maximum depth of the lagoon is approximately 2.5m **(Maanan, 2003)**.

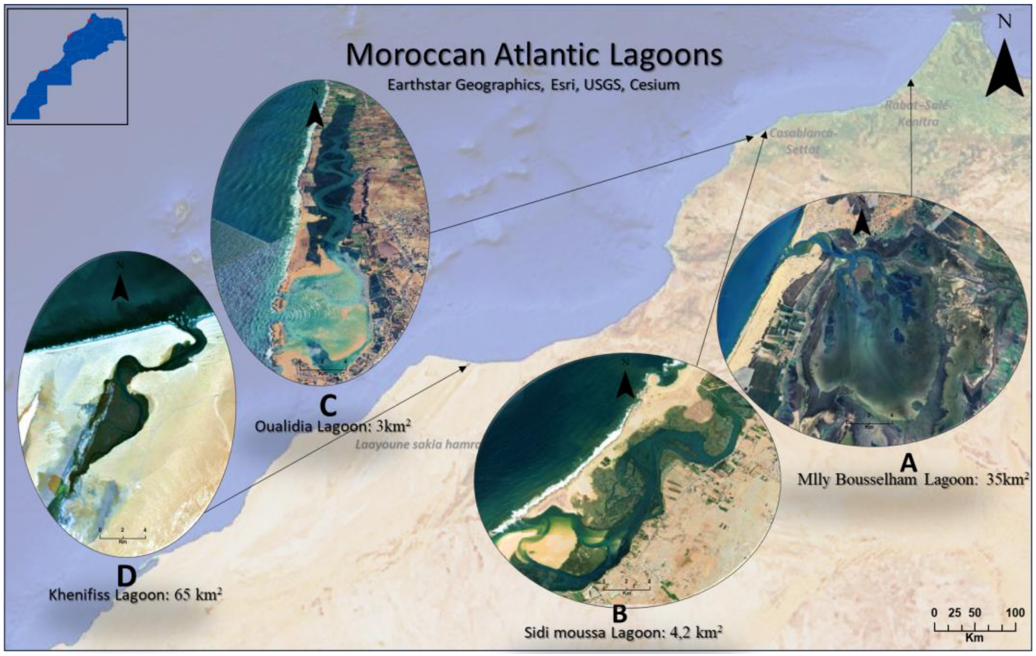

Fig. 2. Distribution of lagoons on the Atlantic coast of Morocco. Map created using ESRI ArcGIS. **(A)** Mlly Bousselham lagoon, **(B)** Sidi Moussa lagoon, **(C)** Oualidia Lagoon, **(D)** Khenifiss lagoon

Oualidia lagoon: The Oualidia lagoon complex, situated on the Moroccan Atlantic coast (32°44′42″ N, 9°02′50″ W) (Fig. 2C), is characterized by a semi-arid climate in the Oualidia region. The lagoon, with a length of 7km and a width of 0.5km, covers a total surface area of approximately $3km^2$, with a total depth of 5-6 meters **(Khalidi *et al*., 2011)**. The Oualidia lagoon communicates with the Atlantic Ocean through three channels, with the main inlet (150m wide and 3m deep, on average) and a secondary inlet (50m wide and 2m deep) and a third small one, which is operational solely during periods of high tides **(Hilmi *et al*., 2004; Bouchkara *et al*., 2023)**. The hydrological regime of the lagoon is dictated by the rhythm of the tides, with minimal freshwater supply **(Beaubrun, 1972)**. According to **Hayes (1975)**, this lagoon is classified as mesotidal; **Postma (1969)** considers it neutral, while **Nichols and Allen (1981)** describe it as estuarine. Adding to its significance, the Oualidia lagoon has been classified as a RAMSAR site since 2005. It holds the status of being one of Morocco's most crucial paralic ecosystems.

Khenifiss lagoon: The Khenifiss (or Naïla) lagoon is located in the south-western part of Morocco's Atlantic coast (28°02’54’’N, 12°13’66’’°W), near Tarfaya, province of Laâyoune, South Morocco (Fig. 2D). Its total surface area is estimated at around $65km^2$, with a length of 20km and a width of hundreds of kilometers. Characterized by a Saharan climate, the Khenifiss region experiences tides and prevailing trade winds, reaching speeds of up to 34m/ s, with the most robust winds originating from the northeast **(André *et al*., 1975; Lakhdar Idrissi *et al*., 2004)**. Additionally, the Khenifiss lagoon is a vast coastal brackish lagoon with mudflats surrounded by coastal sand dunes and various inland saline areas **(Dakki & Parker, 1988)**. Upstream, the Khenifiss lagoon is bounded by the Sebkha TAZGHA, a significant flat-bottomed saline basin that is considered the most important in the Moroccan Sahara for salt exploitation, with reserves estimated at 4.5 million tonnes **(Chmourk, 2012)**. The Khenifiss lagoon is separated from the Atlantic Ocean by a narrow dune belt opened by a single pass called "Foum Agouitir" **(Beaubrun, 1976)**. This lagoon is anti-estuarine salt **(Postma, 1969)**, microtidal **(Hayes, 1975)**, and semi-closed **(Nichols & Allen 1981)**. This lagoon is designated as a Ramsar site in 2019 and it is currently part of the RESCOM project «Enhancing Ecosystem Resilience in the Mediterranean», supported by the Mediterranean Biodiversity Consortium and the National Agency of Water and Forests (ANEF) - Morocco, which aims to enhance the Khenifiss National Park in Morocco by promoting ecotourism and preserving its exceptional biodiversity.

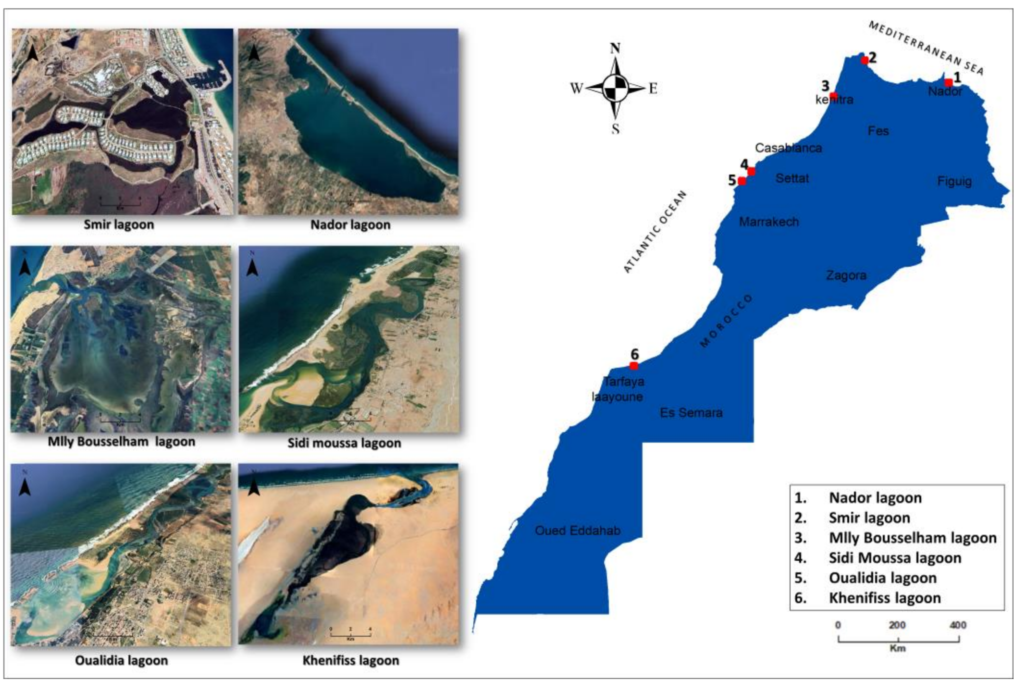

Fig. 3. Geographical distribution of the Atlantic and Mediterranean lagoons of Morocco

Table 1. Geographical location and morphological framework of Moroccan lagoons (Mediterranean and Atlantic)

Lagoons	**Nador**	**Smir**	**Moulay Bousselham**	**Sidi Moussa**	**Oualidia**	**khenifiss**
Area	115 km^2	8,37 km^2	35 km^2	4,2 km^2	3 km^2	65 km^2
Geographic coordinates	(2°45'N – 2°55'N, 35°10'W)	(35°41'48"N 05°22'02"W)	(34°48'N - 34°53'N, 6°16'W - 6°19'W)	(32° 52' 0''N, 8° 51' 05''W)	(32°46'N, 09°01'W)	(28°02'54''N, 12°13'66''W)
Climat	Semi-aride	Semi-aride	Semi-aride	Semi-aride	Semi-aride	Saharan
Inlet	Single (250m wide)	Single	Single	Two inlets (main: 200m wide and secondary: 50m wide)	Three inlets (main: 150m wide, secondary 50 m wide and tertiary: small one)	Single
Length	25 km		9km	5.5km	7km	20km
Width	7,5km		5km	0.5km	0.5km	Hundred meters
Lagoon type	- Anti-estuarine -Semi-closed - Microtidal	Neutral	-Semi-closed -Microtidal	-Neutral -Estuarine -Mesotidal	-Neutral -Estuarine -Mesotidal	-Anti-estuarine -Semi-closed -Microtidal
Maximum depth	8 m	0,5 m	2 m	2,5 m	5-6 m	8 m

2. Heavy metal contamination of coastal lagoons

Measured concentrations of copper (Cu), chromium (Cr), lead (Pb), zinc (Zn), cadmium (Cd), and nickel (Ni) in the six Moroccan lagoons are presented in Table (2), revealing varying levels of contamination across these ecosystems.

Nador lagoon: The Nador Lagoon ranks among the most contaminated lagoons, with notably high concentrations of copper (Cu), chromium (Cr), lead (Pb), and zinc (Zn) as presented in Table (2). Industrial and agricultural activities, along with urban discharges, are presumed to be significant contributors to this multifaceted contamination **(Maanan *et al*., 2015)**. These findings underscore potential environmental repercussions and warrant further investigation into the sources of metal contamination.

Smir lagoon: Although heavy metal levels in Smir lagoon are generally lower than in other lagoons, the presence of cadmium raises concerns, necessitating further monitoring. The contamination in Smir lagoon is associated with various human activities. The construction of dams on the Smir River has led to a reduction in the marshes' floodplain area, prompting local residents to drain the land for agriculture, particularly vegetable cultivation. The use of fertilizers and pesticides in this agricultural practice introduces pollutants into the environment. Additionally, changes in livestock farming from extensive grazing in the marshes to intensive farming with dairy breeds raised in stables have further contributed to environmental degradation. These activities result in the flow of pollutants from the marshes into the lagoon and ultimately into the sea **(Bayed & Chaouti, 2005; Khattabi & Sefriti, 2005)**.

Moulay Bousselham lagoon: Metal concentrations in Moulay Bousselham were generally lower, except for zinc (Zn) (210mg/ kg). The pollution of metals in the Moulay Bousselham lagoon are introduced into the environment through a combination of natural processes and anthropogenic sources. **(Mhamdi Alaoui *et al*., 2010)**.

Sidi moussa lagoon: Our dataset indicates elevated concentrations of chromium (Cr) and copper (Cu) compared to other lagoons. The increased metal concentrations observed are predominantly linked to the utilization of phosphate fertilizers and pesticides in agricultural operations **(John, 2008)**. Furthermore, the close proximity of the lagoon to industrial phosphate plants elucidates the notably heightened values of cadmium (Cd).

Oualidia lagoon: In general, the Oualidia lagoon has lower concentrations of heavy metals than other lagoons. Although an in-depth assessment of pollutant inputs has not been undertaken, the main sources of pollutants have been identified. They stem from a variety of human activities, including the ongoing development of oyster farming, which began in this lagoon in 1950, as well as contributions from agriculture, fishing and tourism **(Maanan *et al*., 2010)**. These sources should be prioritized in remediation initiatives.

Khenifiss lagoon: The Khenifiss lagoon stands out as the most impacted of all the lagoons studied by cadmium (Cd) and Ni contamination. No study to date has identified the exact source of this metal contamination, given that the ecosystem is far from any anthropogenic pressure. The potential cause could be linked to the proximity of the main national highway, the presence of vehicles and machinery utilized in the nearby saltworks, and the operation of small harbors primarily dedicated to fishing. Furthermore, it is reasonable to attribute industrial emissions from the Atlantic coast of Morocco and neighboring countries as additional contributors to the observed enrichments **(Tnoumi *et al*., 2022)**. Despite these factors, anthropogenic activities and the threats they pose to the Khenifiss lagoon are less concerning than to other Moroccan lagoons. This is due to the small size of the local population, which reduces human pressure on the ecosystem, the strict legislation protecting the area from excessive resource exploitation, and the limited access to the ecosystem **(El Mahrad *et al*., 2020)**.

These findings accentuate the intricacies inherent in contamination sources within each lagoon, necessitating the implementation of integrated environmental management strategies, sustained monitoring, the enforcement of discharge regulations, and advocacy for sustainable agricultural practices are indispensable to mitigate the deleterious impact of pollutants on marine ecosystems and uphold the overall health of the lagoons.

Table 2. Comparison of metal concentration measurements in six Moroccan lagoons

Lagoon	Cu	Cr	Pb	Zn	Cd	Ni	Reference
Nador	37.5	55.0	20.0	70.0	0.30	nd	**Maanan *et al*. (2015)**
Smir	12	nd	nd	56	0.15	nd	**Messari *et al*. (1994)**
Moulay Bousselham	55	47	28	210	0.2	28	**Maanan *et al*. (2013)**
Sidi moussa	30	45	nd	45	0.20	nd	**Boutahar *et al*. (2019)**
Oualidia	5.27	43.47	0.71	23.57	0.127	19	**Mejjad *et al*. (2018)**
Khenifiss	17	63	6.8	69	0.37	35	**Idardare *et al*. (2013)**

Unit: mg/kg - nd: not determined

3. Physico-chemical and hydrodynamic characteristics

The physico-chemical and hydrodynamic features of the six Moroccan lagoons exhibit notable diversity (Table 3), indicative of the influence of various environmental and anthropogenic factors on these coastal ecosystems.

Temperature variations are noteworthy, with the highest recorded values observed in the Nador and Smir lagoons, situated in the Mediterranean coastal regions. Elevated temperatures in these lagoons can be attributed to human activities such as agricultural drainage and wastewater discharged into the lagoon **(Hajib & Bayed, 2005)**.

Continuing with the comparative analysis of salinity levels, the Nador, Smir and Khenifiss lagoons are characterized by high salinity levels, compared to other Moroccan lagoons. In the specific case of the upstream Khenifiss lagoon (39.4 psu), the particularly high salinity can be attributed to the presence of a salt deposit (Sebkha Tazgha) combined with the absence of a significant freshwater input **(Lakhdar *et al*., 2004)**. For the Nador and Smir lagoons, the increase in salinity can be influenced by human activities, notably intensive agriculture and industrial water exploitation.

Comparative analysis of dissolved oxygen levels and nutrient concentrations in the lagoons reveals significant variations. The Oualidia and Khenifiss lagoons exhibit the highest concentrations of both dissolved oxygen and nutrients compared to other lagoons

(Table 3). This enrichment can be attributed to the influence of the upwelling phenomenon, characterized by the upwelling of cold deep waters, highly rich in nitrogen and phosphate elements **(Lakhdar *et al*., 2004)**. However, the relatively lower dissolved oxygen concentrations observed in the Nador lagoon may be consistent with the low dissolved oxygen levels in the Mediterranean Sea. This observation establishes a continuity in the levels observed within this specific lagoon ecosystem **(Idrissi *et al*., 2020)**.

In the studied lagoons, current velocities follow a distinct pattern, with peak speeds observed at the inlet and gradually decreasing towards the upstream of the lagoon. Remarkably, the highest maximum velocities are documented in the Khenifiss and Oualidia lagoons (1.2m/ s and 0,91m/ s) (Table 3). The velocity of currents in these lagoons closely correlates with tidal variations (neap and spring tides), exhibiting an increase at high tide and a decrease at low tide **(Bouchkara *et al*., 2023)**.

The physico-chemical and hydrodynamic conditions of the studied lagoons are ideal for supporting aquaculture, offering a diverse and sustainable marine environment for shellfish, fish and seaweed farming. One of the key challenges facing lagoon aquaculture is the potential for eutrophication, an overabundance of nutrients that can lead to harmful algal blooms and disrupt the balance of the ecosystem **(Kang *et al*., 2021)**. This underscores the importance of implementing strategies to mitigate nutrient loading and manage water quality within lagoon aquaculture areas.

Table 3. Physico-chemical and hydrodynamic properties of the Moroccan lagoons

Lagoon/ parameter	**Temperature**	**Salinity**	**Dissolved oxygen**	**Nutrient content**	**Current speed**	**Reference**
Nador	23,1°C and 29,8°C	37,3psu	2,34 et - 5,22mg/l	PO_4: 0.6 µg/l NO_3:3,5 µg/l	At the inlet (> 1 m/s) At the center of the lagoon (<. 0.5 m/s) Towards the lagoon's continental shores (< 0.3 m/s).	**Hilmi *et al*. (2015), Idrissi *et al*. (2020)**
Smir	14,7 and 32°C	30-40 psu	8,5 à 12 mg/l	NO_3: 1,1 et 41 µg/l	Reaching up to 0.8 m/s before the implementation of the developments and nearly zero afterward.	**Messari & Bosch (1995), Bayed & Chaouti (2005)**
Moulay	17,6 and 23	24 ‰ to	-	-	0.55 m/s in low	**Beaubrun**

Bousselham	°C	36.28 ‰ at high tide and 8 ‰ to 32.52 ‰ at low tide			tide and 0.9 m/s in high tide	**P.C. (1976), Labbardi *et al*. (2005)**
Sidi moussa	15,9 and 24°C	36 psu	5.81 mg/l et 13.17 mg/l	PO_4:8.5 µg/l NO_3: 22,3 µg/l	0,1 m/s 0,25 à. 0,75 m/s	**Maanan. (2003), Kaddioui *et al*. (2018)**
Oualidia	14,6 and 23,6°C	35psu	8,77mg/l et 10,02mg/l	PO_4: 11.6 µg/l NO_3: 21,6 µg/l	At the inlet: 1.2 m/s Upstream: 0.7 m/s.	**Hilmi *et al*., (2004), Kaddioui *et al*. (2018), Somoue *et al*. (2020), Damsiri *et al*. (2022), Bouchkara *et al*. (2023)**
Khenifiss	18.9- 23.2 °C	Downstream: 35psu Upstream :39.4 psu	7 mg/l	PO_4:97 µg/l; $NO_{3:}$ 80 µg/l - 6,9 µg/l;	At the inlet: 0,91m/s Upstream: 0,42 m/s	**El Agbani *et al*. (1988), Lakhdar *et al*. (2004), Malainine *et al*. (2013)**

4. The marine biological wealth of Moroccan lagoons and main species recommended for aquaculture

To gain insight into the biodiversity of Moroccan lagoons, we conducted an examination of the data presented in Tables (4, 5), which catalog species including fish, crustaceans, mollusks, polychaetes, echinoderms, and macroalgae.

The distribution of marine species varies among Moroccan lagoons, reflecting the specific environmental requirements of each species and its tolerance to physicochemical parameters.

Based on our analysis of data from prior studies, we have found that the Oualidia lagoon closely resembles Khenifiss, with a notable predominance of mollusks, followed by crustaceans and polychaetes. In the Khenifiss lagoon, mollusks dominate, comprising 96.1% of the total benthic fauna. Notably, two species are particularly dominant: *Hydrobia ulvae* and *Turritella communis* **(Lefrere *et al*., 2015)**. The dominant species in Oualidia lagoon are *Hydrobia* sp. followed by *Abra alba*, *Nassarius pfeifferi* and *Cerastoderma edule* **(El Asri *et al*., 2015)**. The common species between Khenifiss and Oualidia lagoons consist of *Eurydice pulchra*, *Ostracoda* and *Solen marginatus*, as indicated in Fig. (4).

In terms of biodiversity, the Nador and Sidi Moussa lagoons also exhibit significant similarities. However, the dominant species in the Nador lagoon are *Capitella capitata*, *Corbula gibba*, *Brachydontes marioni*, *Loripes lacteus* and *Bittium reticulatum* **(Guelorget *et al*., 1987)**. Notably, common species between the Nador and Sidi Moussa lagoons include *Carcinus maenas, Pachygrapsus marmoratus, Cerastoderma glaucum* and *Capitella capitata.*

Conversely, the lagoons of Smir and Moulay Bousselham present distinct profiles, with crustaceans as the dominant group, followed by polychaetes and then mollusks. In Smir, prominent species include *Melita palmata, Cyathura carinata, Sphaeroma hookeri, Corophium acherusicum,* and *Hediste diversicolor* **(Chaouti & Bayed, 2005)**. On the other hand, in Moulay Bousselham, the key species are *Heteromastus filiformis*, *Scrobicularia plana* and *Nassarius reticulatus* **(Bazaïri *et al*., 2003)**. Additionally, The common species between Smir and Moulay Bousselham lagoons include *Corophium acherusicum, Sphaeroma hookeri, Tanaïs dulongii, Corophium orientale, Tellina tenuis* and *Notomastus latericeus* and *Heteromastus filiformis.*

Table 4. The biological richness of Moroccan lagoons (Fish, crustaceans, mollusks, polychaetes and echinoderms).

Lagoon	Fish	Crustaceans	Mollusks	Polychaetes	Echino-derms	Reference
Nador	*Sparus aurata* *Dicentrarchus labrax* *Atherina presbyter* *Salaria pavo* *Callionymus risso* *Pomatoschistus marmoratus* *Gobius niger* *Hyporhamphus picarti* *Symphodus cinereus* *Symphodus tinca* *Dicentrarchus punctatus* *Liza aurata* *Mullus barbatus* *Solea barbâtes* *Diplodus puntazzo* *Syngnathus typhle* *Syngnathus abaster*	*Carcinus maenas* *Pinnotheres pinnothères* *Eriphia verrucosa* *Corophium insidiosum* *Gammarus gr. Locusta* *Microdeutopus gryllotalpa* *Pachygrapsus marmoratus*	*Cerastoderma glaucum* *Scrobicularia plana* *Tapes decussata* *Hydrobia ulvae* *Haminoea navicula* *Pondylus gaederopus* *Ostreaedulis* *Pinna nobilis* *Jujubinus gravinae* *Gibbula ardens* *Tiny Tricolia* *Bittium reticulatum* *Cerithium vulgatum* *Hexaplex trunculus* *Murex brandaris* *M. trunculus* *Ostrea edulis* *Corbula gibba* *Brachydontes marioni* *Loripes lacteus*	*Nephtys hombergii* *Hediste diversicolor* *Lumbrineris impatiens* *Capitella capitata* *Eunice pennata* *Glycera convoluta* *Harmothoe spinifera* *Lumbriconereis impatiens* *Nereis caudata* *N. diversicolor* *Nerine foliosa* *Pectinaria koreni* *Scolelepis ciliata*	*Paracentrotus lividus* *Cucumaria planki* *Holothuria polii* *Ophiuridae*	**Clanzig (1989), Guelorget *et al*. (1987)**
Smir	*Syngnathus acus*	*Leptostracans :*	*Bivalves : Acanthocardia*	*Alkmaria romijni*	*Amphipholis squamata*	**Chaouti & Bayed**

	Gobiidae indét	*Nebalia bipes* *Tanaïdacés :* *Tanaïs dulongii* *Décapodes :* *Carcinus maenas* *Palaemon elegans* *Palaemonotes varians* *Mysidaceae:* *Mysis* sp *Isopods :* *Cyathura carinata* *Cylisticus cf. convexus* *Dynamene cf. bidentata* *Sphaeroma hookeri* *Amphipods :* *Corophium acherusicum* *Corophium orientale* *Gammarus chevreuxi* *Gammarus pulex* *Leptoccheirus pilosus* *Melita palmata* *Orchestia gammarella* *Talitrus saltator* *Talorchestia deshayesii* *Urothoe pulchella*	*echinata* *Cerastoderma glaucum* *Crassostrea gigas (introduced species)* *Loripes lucinalis* *Modiolus phaseolinus* *Scrobicularia plana* *Tapes decussata* *Tellina sp.* *Tellina tenuis* *Gastéropodes* *Actaeon tornatilis* *Aplysia depilans* *Bittium reticulatum* *Haminoea navicula* *Hydrobia ulvae* *Physa acuta* *Physa fontinalis* *Rissoa parva* *Skeneia planorbia* *Turboella dolium*	*Amphitrite gracilis* *Hediste diversicolor* *Heteromastus filiformis* *Laeonereis glauca* *Lumbrineris impatiens* *Mercierella enigmatica* *Nephtys hombergii* *Notomastus latericeus* *Polydora giardi* *Scolelepis* sp. *Streblospio* sp	*Paracentrotus lividus*	**(2005)**
Moulay Bousselham	*Anguilia anguilla* *Laphius sp.* *Solea semegalensis*	*Carcinus maenas* *Caridea sp2* *Corophium acherusicum* *Melita palmata* *Sphaeroma hookeri* *Cyathura carinata* *Tanaïs dulongii* *Caprellidae unidentified* *Cirripedia unidentified* *Cumacea sp.* *Amphitoe*	*Scrobicularia plana* *Tapes decussata* *Hydrobia ulvae* *Haminoea navicula* *gastropoda* *Opistobranchia* *Crassostrea gigas* *Spisula subtruncata* *Musculus costulatus* *Tellina tenuis* *Venerupis pullastra*	*Alkmaria romijni* *Nephtys hombergii* *Hediste diversicolor* *Notomastus latericeus* *Heteromastus filiformis* *Capitella capitata* *Polydora ciliata* *Polyphthalmus pictus*	*Paracentrotus lividus* *Ophiuroidea unidentified*	**Bazaïri *et al*. (2003)**

		ramondi *Aphelusa jurinei* *Corophium acutum* *Corophium orientale* *Dexamine spinosa* *Elasmopus* sp.				
Sidi Moussa	Data insufficient	*Urothoe grimaldi* *Microdeutopus chelifer* *Melita palmata* *Monodanthura maroccana* *Cyathura carinata* *Idotea chelipes* *Crangon chipies* *Carcinus maenas* *Pachygrapsus marmoratus* *Palaemon serratus* *Uca tangeri*	*Venerupis decussatus, Cerastoderma edule, Ensis ensois Hydrobia Ventvosa Cerastoderma glaucum*	*Nereis diversicolor* *Capitella capitata* *Neanthes caudata* *Diopatra neapolitana* *Scoloplos armiger* *Mysta picta* *Malacoceros fuliginosus*	Data insufficient	**El Asri *et al*. (2015, 2023)**
Oualidia	Data insufficient	*Carcinus maenas* *Palaemon elegans* *Melita palmata* *Corophium* sp. *Caprella liparotensis* *Ampithoe* sp. *Gammaridae* *Cyathura carinata* *Idotea balthica* *Eurydice pulchra* *Sphaeroma serratum* *Tanais dulongii* *Apseudes* sp. *Cumacea* *Copepoda* *Ostracoda* *Pagurus bernhardus* *Balanus* sp.	*Aplysia punctat* *Scrobicularia plana* *Tapes decussata* *Cerastoderma glaucum* *Solen marginatus* *Cerastoderma edule* *Loripes lucinalis* *Loripes orbiculatus* *Abra alba* *Ruditapes decussatus* *Venerupis pullastra* *Spisula subtruncata* *Mytilis galloprovin-cialis* *Patella rustica* *Cymbula safiana* *Patella depressa* *Haminoea japonica* *Gibbula umbilicalis* *Phorcus*	*Nephtys hombergii* *Hediste diversicolor* *Alkmaria romijni* *Capitella* sp. *Diopatra cf. marocensis* *Glycera alba* *Phyllodoce sp.*	*Paracentrotus Lividus* *Holothuria poli* *Ophiura* sp.	**Kersten *et al.* (1981), El Asri *et al*. (2020)**

			lineatus *Phorcus sauciatus* *Myosotella myosotis* *Dendrodoris sp.* *Nassarius pfeifferi* *Hydrobia sp* *Epitonium clathrus* *Jorunna tomentosa* *Lepidochitona cinerea* *Mytilus galloprovincialis* *Octopus vulgaris* *Onchidella celtica* *Patella depressa* *Patella rustica* *Peringia ulvae*			
Khenifiss	*Sparisoma cretense* *Sea bass* *Sole* *Sparus aurata* *Gilthead seabream* *Mugil capurii (African mullet)* *Mustelus must élus.*	*Ampelisca brevicornis* *Anpelises diadems* *Ampelisca Spinipes* *Ampithoe ramandi* *Artemia salina* *Corophiun acutus* *Eurydice pulchra* *Haustorius srenarius* *Leucathoe incisa* *Leucothoe richiardii* *Lysianasse cerating* *Idoteicse* *Ostracoda* *Photis sp* *Pontecrates altemsrinus* *Tanaidacea*	*Abra tenuis* *Cerastoderma edule* *Crassostrea gigas* *Diploganta rotundata* *Haminea orbdignyana* *Solen marginatus* *Hydrobia ulvae* *Turritella communis*	*Audovinia tentaculsta* *Clymene oerstedii* *Diopatra neepolicana* *Hediste diversicolor* *Lapnome keoyeri* *Lysidice sp* *Marohysa sanguinea* *Melinna palmsta* *Nephtys hombergii* *Nereis diversicolor* *Notomastus sp* *Pista cf. maculata* *Scoloples arsiger* *Diopatra neapolitana,* *Terebella lapidaria* *Nicomache lumbricalis*	*Ophiurs sp*	**Bayed *et al*. (1988), Lefrere *et al.* (2015)**

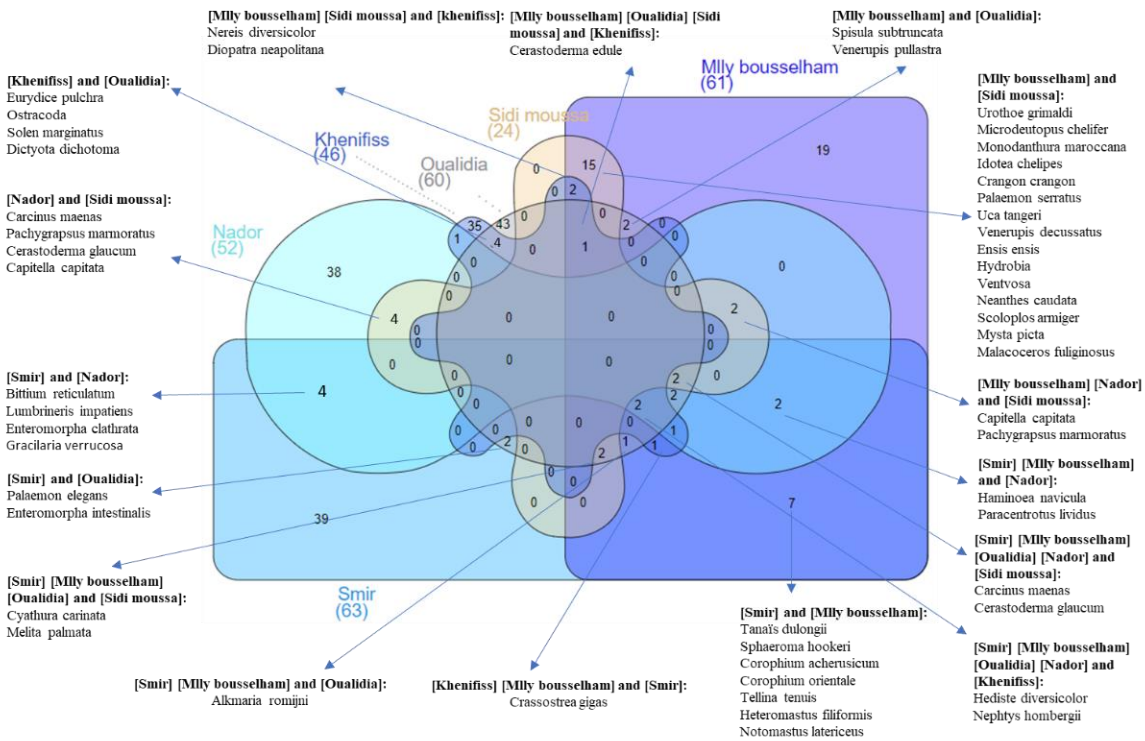

Fig. 4. Venn diagram illustrating overlaps of common species across Moroccan lagoons (Created with InteractiVenn) **(Heberle *et al*., 2015)**

For macroalgae species in Moroccan lagoons, the class Rhodophyta stands out as the most dominant, showcasing the highest species richness. This class comprises twelve notable groups, including Alsidiales, Acrochaetiaceae, Cystocloniaceae, Gelidiaceae, Gracilariaceae, Bangiaceae, Ceramiaceae, Gigartinaceae, Rhodomelaceae, Phyllophoraceae, Laurenciaceae, Corallinaceae. Among these, the Gracilariaceae family is particularly dominant, with several species of red algae that are well-suited for seaweed farming, as detailed in Table (6). The Chlorophyta and Phaeophyta classes follow in abundance, with Phaeophyta represented by eight families (Cystoseiraceae, Ectocarpaceae, Sargassaceae, Dictyotaceae, Fucaceae, Bifurcariaceae, Scytosiphonaceae and Delesseriaceae) and Chlorophyta comprises six families (Blidingiaceae, Caulerpaceae, Cladophoraceae, Ulvaceae, Codiaceae, Valoniaceae and Ulvaceae).

Table 5. Summary of macroalgae species richness in the Moroccan lagoons

Lagoon/Family	CHLOROPHYTA	PHAEOPHYTA	RHODOPHYTA	Reference
Nador	*Blidingia marginata (J. Agardh) P.J.L.Dangeard ex Bliding* *Caulerpa prolifera,* *Chaetomorpha sp.,* *Enteromorpha clathrata* *Enteromorpha compressa*	*Cystoseria sp.* *Cystoseira compressa (Esper) Gerloff & Nizamuddin* *Cysteseira barbata (Stackhouse)* *Cystoseira crinita Duby*	*Alsidium corallinum C. Agardh* *Audouinella codii (G. Hamel) G.Furnari* *Audouinella daviesii (Dillwyn) Woelkerling* *Audouinella*	**Ramdani *et al*. (2015)**

	Enteromorpha flexuosa *Uulva sp.* *Rhizoclonium riparium (Roth) Harvey*	*Ectocarpus siliculosus (Dillwyn) Lyngbye* *Sargassum vulgare C. Agardh*	*moniliformis (Rosenvinge) Garbary* *Caulacanthus ustulatus (Mertens ex Turner) Kützing* *Gelidium latifolium Bornet ex Hauck* *Gracilaria armata (C. Agardh) Greville* *Gracilaria bursa-pastoris* *Gracilaria cervicornis* *Gracilaria verrucosa Papenfuss* *Rytiphleatinctoria.*	
Smir	*Cladophora albida* *Cladophora vagabunda* *Enteromorpha clathrata* *Enteromorpha intestinalis* *Enteromorpha linza* *Ulva fasciata* *Ulva lactuca* *Ulva rigida*	*Ectocarpus confervoides*	*Bangia atropurpurea* *Ceramium diaphanum* *Chondracanthus asicularis* *Gracillaria verrucosa* *Potamogeton pectinatus* *Rupia maritima* *Zostera noltii* *Cymodocea nodosa*	**Benhissoune *et al.* (2005)**
Moulay bousselham		Data insufficient		
Sidi moussa				
Oualidia	*Codium tomentosum Stackhouse,* *Enteromorpha intestinalis (Linnaeus) J. Agardh,* *Ulva lactuca C. Agardh.*	*Bifurcaria bifurcata Ross,* *Cystoseira humilis Kutzing,* *Cystoseira tamariscifolia (Hudson) Papenfuss,* *Dictyota dichotoma (Hudson)Lamouroux,* *Fucus spiralis Linnaeus,* *Sarrassum muticum (Yendo) Fensholt.*	*Asparagopsis armata Harvey,* *Corallina officinalis Ellis andSolander,* *Gracilaria gracilis* *Gracilaria longissima* *Gracilaria multipartita* *Gelidium sesquipedale (Turner),* *Halopitys incurvus (Hudson)Batters,* *Hypneamusciformis (Wulfen) J.V. Lamouroux,* *Laurencia pinnatifida Hudson,* *Palmariapalmata (Linnaeus) Kuntze,* *Sphaerococcus coronopifolius Stackhouse*	**Farid *et al.* (2012)**
Khenifiss	*Codium elongatum C. A.* *Codium Sp.* *Ulva rigida* *Valonia utricularıs*	*Bifurcaria tuberculata (Huds.)* *Colpomenia sinuosa* *Cystoseira ericoides (Linnaeus)* *Cystoseira humilis var. myriophylloides (Sauv.)* *Cystoseira gibraltarica* *Dictyota dichotoma* *Halopteris filicina*	*Calliblepharis jubata* *Caulacanthus ustulatus* *Ceramium rubrum* *Corallina Mediterranea Ares* *Coralline officinalis* *Gelidium pusillum* *Gracilaria multipartita* *Halopithys pinastroides*	**Russell & Hockin (1988)**

	Helminthora divaricata
	Jania rubens (L.) Lamour.
	Laurencia caespitosa Lamour
	Laurencia pinnatifida (Gmel.) Lamour
	Phyllophora rubens (Good et Wood) Grev.
	Plocamium coccineum (Huds.) Lyn.
	Pterocladia capillacea (Gmel.) Thur. et Born.
	Scinaia furcellata (Turner)

Table (6) shows the species promoted for aquaculture in Moroccan lagoons and recommended by the National Agency for Aquaculture Development (ANDA). It's pertinent to note that all these species are indigenous, a fact supported by the information provided in Tables (4, 5) and they have strong commercial value.

The recommendations are divided into four categories: fish farming, shellfish farming, shrimp farming and seaweed farming. Each species is paired with the lagoons where it can be successfully cultivated and where it demonstrates adaptability to local conditions.

- Fish farming:

The sea bass (*Dicentrarchus labrax*) of the Moronidae family and the gilthead sea bream (*Sparus aurata*) of the Sparidae family are among the most economically important species, valued highly in Mediterranean regions as well as worldwide **(Chatain *et al*., 2009)**. The production of these two species has seen significant growth, with Turkey, Greece, and Egypt emerging as the leading producers, collectively accounting for the majority of global output **(Zoli *et al*., 2023)**. Notably, over 95% of the global supply of the sea bream and sea bass is derived from aquaculture **(Zoli *et al*., 2023)**. The primary grow-out farming method for both species involves the use of submerged cages in marine environments. According to Table (6), these species are also recommended for fish farming in Moroccan lagoons, particularly in the Nador lagoon.

- Shellfish farming:

Crassostrea gigas: It is a bivalve mollusk from the Ostreidae family. Native to the Pacific coast of Asia, it is now one of the most widely farmed oysters in the world. *C. gigas* lives in marine environments, feeding on plankton, and is very adaptable to different ecological conditions. This makes it an important species in aquaculture, supporting local economies and helping to maintain healthy marine ecosystems **(Sühnel *et al*., 2024)**.

Cerastoderma edule: It is a member of the Cardiidae family, particularly appreciated as a food source, making it of great economic value. It achieves sexual maturity in 1 to 2 years, making it ideal for aquaculture by supporting fast reproduction and effective population control **(Mesquita *et al*., 2023)**.

Ruditapes decussatus: It is also known as the European clam, and belongs to the Veneridae family. This species is widely distributed along the Mediterranean and Atlantic coasts, from the Lofoten Islands (Norway) to Mauritania. It lives in warm coastal waters, particularly lagoons **(Ghiselli *et al*., 2017)**.

Mytilus galloprovincialis: The blue mussel (*Mytilus galloprovincialis*) is a bivalve mollusk, and belongs to the Mytilidae family, commonly found on the Mediterranean and Atlantic coasts. This species is cultivated in suspension in coastal waters and is valued for its filtration capacities, thus helping to improve water quality **(Oyarzún *et al*., 2024)**.

The farming of these species is recommended in various Moroccan lagoons, such as the Nador lagoon, Moulay Bousslham lagoon, Sidi Moussa lagoon, Oualidia lagoon, and Khenifiss lagoon.

- Shrimp farming:

Artemia salina: *Artemia*, a microscopic crustacean from the *Artemiidae* family, thrives in saline environments and is extensively used as live feed in aquaculture, especially for the larvae of marine species. It plays a crucial role in aquatic food webs and reproductive cycles. To culture *Artemia* effectively, a suitable nutrient source, such as rice bran, is essential to promote its growth **(Cahyani Prasetyawati *et al*., 2024)**. The farming of this species is only recommended in the Khenifiss lagoon.

- Seaweed farming:

Gracilaria spp.: Species of the *Gracilaria* Greville genus, such as *Gracilaria gracilis*, *Gracilaria verrucosa*, and *Gracilaria multipartita*, belong to the Gracilariaceae family, a group of red algae (rhodophytes) **(Capillo *et al*., 2017)**. For cultivation, Gracilaria is primarily grown in suspension, attached to ropes supported by buoys. These algae are particularly valued for agar-agar extraction, a gelling agent used in the nutrition, pharmaceutical, and cosmetic industries **(Mouedden *et al*., 2024)**. The farming of these species is recommended in several Moroccan lagoons, including the Nador lagoon (*Gracilaria verrucosa*), Smir and Oualidia lagoons (*Gracilaria gracilis)*, and Khenifiss lagoon (*Gracilaria multipartita*).

Table 6. Types of aquaculture and species recommended for aquaculture farming in Moroccan lagoons

Type of aquaculture	Species	Favorable lagoon
Fish farming	*Dicentrarchus labrax* *Sparus aurata*	Nador
Shellfish farming	*Crassostrea gigas* *Cerastoderma edule* *Ruditapes decussatus* *Mytilus galloprovincialis*	Nador Moulay Bousselham Sidi moussa Oualida Khenifiss
Shrimp farming	*Artemia salina*	Khenifiss
Seaweed farming	*Gracilaria verrucosa* *Gracilaria gracilis* *Gracilaria multipartita*	Nador Smir Oualida Khenifiss

5. The importance of coastal lagoons in Moroccan fisheries and aquaculture

Fisheries and aquaculture activities play a significant role in the coastal regions of Morocco, particularly in lagoons, due to their nutrient richness, natural protection against oceanic elements, and abundant biodiversity.

The Nador Lagoon stands out as a prime example, boasting unique environmental conditions that make it an ideal location for aquaculture development. It has supported historically artisanal fishing as a prominent activity in the lagoon, and fostered the growth of aquaculture ventures due to its natural assets. The introduction of intensive farming, focusing on shellfish such as oysters and clams, as well as fish species like the royal sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*), dates back to the mid-1980s with the MAROST (Moroccan Society for Ostreiculture) project. Since then, aquaculture has become an essential component of the local economy, providing employment opportunities and contributing to the region's food security. Over the last decade, Nador fishermen have increased their catches, with about 46% engaging exclusively in fishing and 54% participating in seasonal work like agriculture **(Najih *et al*., 2015)**. In 2017, fish catches totaled 5962 tons, with aquaculture accounting for 13 tons **(Département de la pêche maritime, 2017)**.

Furthermore, it's worth noting that the cultivation of seaweed (particularly the algae *Gracilaria verrucosa)* in the Nador lagoon has garnered significant attention and support from various stakeholders. Supervised by the National Agency for Aquaculture Development (ANDA) since 2013, this initiative is integral to the broader framework of the Integrated Coastal Zone Management (ICZM) process and the Sustainable Med program, spearheaded by the Ministry of the Environment **(Kassila *et al*., 2019)**.

Aquaculture activities are not practiced in the Smir lagoon, and fishing has also ceased, especially after the implementation of recent developments.

In Moulay Bousselham lagoon, artisanal fishing stands out as one of the main activities, with a catch of 96 tons in 2017, highlighting its significance **(El Mahrad *et al*., 2020)**. Additionally, clam harvesting is the primary activity in Moulay Bousselham lagoon. Due to overexploitation, clam stocks are at risk of depletion. It's crucial to manage resources sustainably and implement extensive aquaculture for stock replenishment. Intensive aquaculture, targeting the European market, should be considered in later phases.

Sidi Moussa and Oualidia lagoons are renowned for shellfish farming, particularly oysters, with the presence of artisanal fishing. Oualidia, in particular, served as the inaugural site for aquaculture in Morocco through shellfish farming in 1950.

Khenifiss Lagoon, characterized by minimal fishing and currently no aquaculture activities compared to other regions. The lagoon is known for its artisanal fishing practices, targeting species like *Diplodus sargus*, *Mugil capurrii, Mustelus mustelus*, and *Anarhichas lupus*. While local fishing contributes to the economy, the absence of aquaculture activities in the lagoon highlights the need for interdisciplinary and multidimensional strategies to support its integrated and sustainable development, particularly for seaweed and shellfish farming, focusing on the exploitation of *Gracilaria multipartita* and *Crassostrea gigas*, as the lagoon offers numerous advantages for aquaculture investments. However, comprehensive studies are needed to assess the sustainability of existing fishing practices and to explore the lagoon's full potential for aquaculture. Limited scientific data currently exist regarding fishing and aquaculture in Khenifiss, underscoring the need for further research to inform sustainable management strategies.

CONCLUSION

In conclusion, this literature review highlights the vital importance of Moroccan lagoons as unique and irreplaceable ecosystems. Their geomorphological diversity, ecological productivity, and crucial role in environmental regulation render them invaluable natural assets that must be preserved. However, given the increasing human pressures and environmental challenges, it is crucial to act swiftly and effectively to safeguard these precious habitats. The Khenifiss lagoon represents a notable exception, being the only lagoon that remains largely untouched by anthropogenic pressures. This uniqueness highlights the urgency of targeted conservation efforts. This analysis identifies key research and knowledge gaps that must be addressed to ensure sustainable management and environmental preservation.

Future research will be instrumental in guiding sustainable development practices, particularly in the responsible integration of aquaculture, including shellfish and seaweed farming. By addressing these research gaps, we can ensure that these valuable ecosystems benefit future generations, while contributing to the growth of a sustainable aquaculture industry in Morocco.

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